Currentodensitogram of SAM virtual sensors compared with simultaneously recorded ECoG

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1 Introduction

Equivalent current dipole (ECD) analysis for magnetoencephalogram (MEG) has been useful in screening the localization of the epileptogenic zone, even though MEG was recorded in the interictal period [1] [2]. However, it requires several mathematical restrictions and often fails to estimate confidential current sources. Therefore the epileptogenic area derived from the ECD analysis might include certain extent of bias.

Recently synthetic aperture magnetometry (SAM) was developed [3] using a beamformer method. It enables to measure the entire sequence of current density in the focused small regions of the brain as if an electrical sensors were placed (virtual sensor, VS)

We applied SAM-VS method to elucidate the origin of the epileptic discharge and compared it with simultaneously recorded electrocorticogram (ECoG).

2 Methods

2.1 ECoG/MEG Recording

A 11-year-old girl with intractable seizure was studied. MRI disclosed pachygyri and atrophy of the left temporal lobe with a small anterior mesial lesion (Fig. 1). Two chronic subdural grid electrodes (SDE), with total of 40 electrodes, were implanted on the lateral and basal surface of the temporal lobe (Fig. 2). Video-ECoG study for 100 hours revealed 20 epileptic onsets arising from the left posterior mesial temporal base among 21 clinical seizures (Fig. 3). Thus the left posterior mesial temporal base was assumed epileptogenic zone.

Interictal MEG was recorded simultaneously with ECoG from the SDE. A total of 40 raw data sets, each of them comprising of 10 seconds recording, were culled from 2 hours recording so as to select the data when the movement of her head position indicated less than 0.3 cm, and to include the epileptic activities on ECoG.

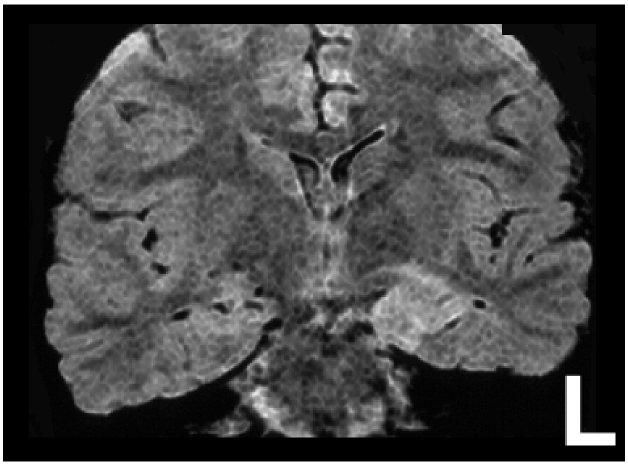

Figure 1: *FLAIR coronal image demonstrates the mild high intensity in the mesial temporal lobe. Focal cortical dysplasia was suspected.*

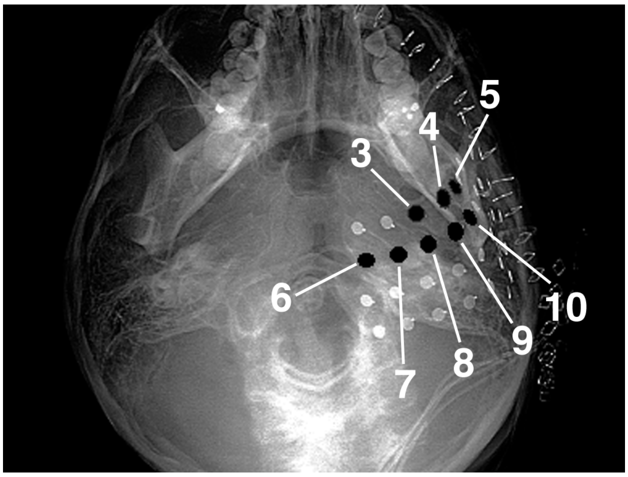

Figure 2: *Skull X-ray image showing the implanted subdural electrodes under the temporal lobe base. The numbered electrodes indicate the ictal onset zone.*

2.2 MEG dipole analysis

A single ECD modeling was used to estimate the source of interictal epileptic spike on MEG. Positions, directions, and dipole moments were computed using the original software supplied by CTF Systems Inc. (B. C., Canada). ECDs were plotted on MR images scanned with the same fiducial markers that were coordinated with the marker points during MEG recording.

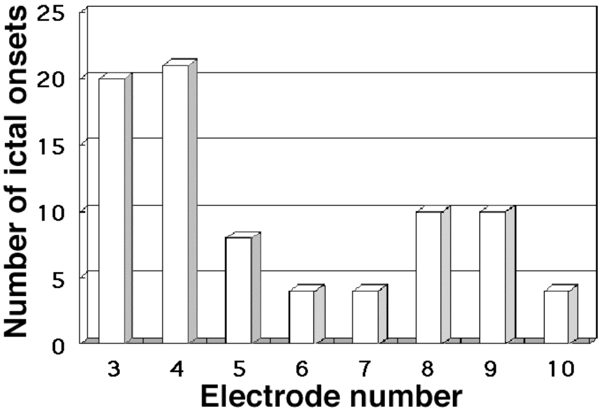

Figure 3: *Number of ictal onsets detected from each subdural electrode. The positions of numbered electrodes are shown in figure 2.*

2.3 Synthetic aperture magnetometry

SAM is a high-resolution spatial filtering based on the algorithm of Frost's adaptive beamformer [4]. It is completely different from the conventional dipole analysis solving inverse problem.

It enables to measure currentodensitogram of the small portion of the brain with an enhanced sensitivity. Then the regional electrical activity of the brain could be measured as if subdural or depth electrodes were inserted (SAM virtual sensor method).

2.2 SAM virtual sensor

A orthogonal coordinate system was adopted to correlate the results of SAM virtual sensor study and ECoG study. The positions of subdural electrodes were marked on the MR images. Lattices of 0.3 cm width were virtually set on the 3 dimensional MR image space. The 30 target points were selected among the points of crossed grids. Each of them was 0.5 cm inside from the cortical surface and the nearest to the corresponding subdural electrode.

The MEG raw data were analyzed to obtain continuous currentodensitogram from each VSs. Currentodensitograms from VSs and ECoG were inspected on the same time axis (Fig. 4). Interictal electrical event was defined as abnormal discharge occurring in the group of two or more electrodes, which were arrayed adjacent to each other. Abnormal discharge was defined as the sudden change of rhythm and strength of the amplitude or moment.

Total of 252 events detected either on ECoG or on VSs were analyzed.

To estimate the sensitivity of SAM-VS method, we examined firstly, the frequency of coincident epileptic discharges on currentodensitogram with those on ECoG, secondly, the frequency of coincident epileptic discharges on ECoG with those on currentodensitogram.

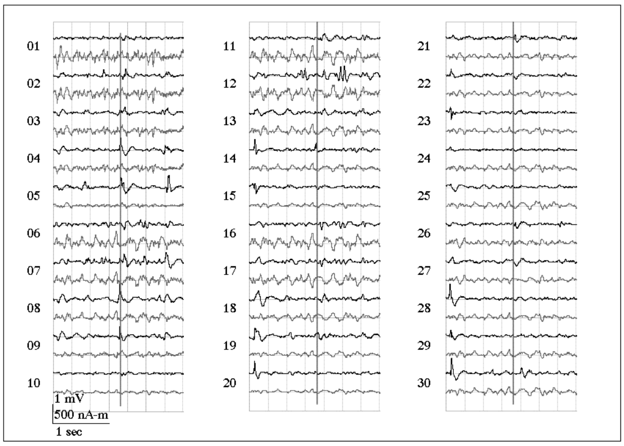

Figure 4: *ECoG (black, upper) and SAM currentodensitogram (gray, lower) on the same time axis. Abnormal electrical activity is observed on the currentodensitogram prior the spike on ECoG (vertical line) from electrodes/ SAM virtual sensor number 6, 7, 11, 12, and 16.*

To estimate the directivity, the electrical abnormal SAM sensors were recruited during the epileptic event detected on the ECoG. The distribution of those SAM sensors was plotted as the frequency in the graph, while the coordinates of the subdural electrode showing the highest amplitude, was set to the origin O of that graph. The center of the distributed SAM sensors was calculated as the moment equilibrium method.

3 Results

3.1 ECoG/MEG Recording

MEG was successfully recorded from the patient with the subdural grid electrodes. Two types of artifacts derived from the electrodes were observed; low amplitude high frequency continuous signals detected from sensors close to the electrodes, and the slow waves accompanying patient's movements. These artifacts were minimized during mathematical process for SAM. When signals of ECoG and MEG were compared, their shapes were usually different. A single spike on ECoG appeared, for example, as a slow wave followed by spike or sharp. Thus the abnormal discharges were detected as the sudden change of rhythm and strength of the amplitude or moment in this study. The signals from the SAM-VSs resembled those of MEG in their wave form, because a SAM-VS was formed out of several MEG sensors.

3.2 Dipole analysis

Interictal magnetic source imaging revealed the scattered distribution of ECDs on the left temporal lobe. Only 4 ECDs were estimated among the MEG abnormal discharges. Directions of their moment, were compatible with those of mesial temporal epilepsy.

3.3 ECoG/SAM comparison

3.3.1 Coincident rate

A total of 252 interictal events appeared on ECoG (Table 1). When interictal abnormal electrical activities occurred, SAM-VSs could detect 68 events (27%) as abnormal electrical activities. On the other hand, when the abnormal electrical activities were observed on the currentodensitogram, 60% of interictal electrical events occurred simultaneously.

3.3.2 Directivity

When epileptic discharge was recorded on both ECoG and SAM currentodensitogram at the same time, the distribution of SAM-VSs showing the abnormal electrical activity was mainly around the sensor coordinate with the electrode yielding the maximum amplitude (Fig. 5). 78% of the frequency was detected through the SAM-VSs within the distance of 1 cm from the datum fiducial axis by coronal sections. On the other hand, 46% was detected also within the distance of 1 cm from the datum fiducial axis by sagittal sections. The statistical first moment indicated 1.6 cm inside and 0.4 cm anterior coordinate from the origin of reference frame.

4 Discussion

We have found the electrical abnormal activities on SAM currentodensitogram coincided well with the epileptic event on the ECoG, both spatially and temporally.

4.1 SAM/ECD comparison

The ECD analysis has been adopted as one of the powerful noninvasive determinants for localization of epileptic focus [5] [6]. It requires, however, a distinct topographical dipole pattern on the MEG field map to estimate appropriate dipole with reasonable confidence. This means that the epileptic discharge being analyzed should have well-ordered phase and should spread in a circular fashion. Thus abnormal discharges representable by ECD might be biased among all abnormal discharges.

Table 1: Coincidence frequency of abnormal discharges on EcoG and SAM-VS currentodensitogram analyzed from 252 epileptic discharges detected on ECoG.

	ECoG	
SAM-VS	positive	negative
positive	68 (27%)	45
negative	184 (73%)	**
Total	252 (100%)	**

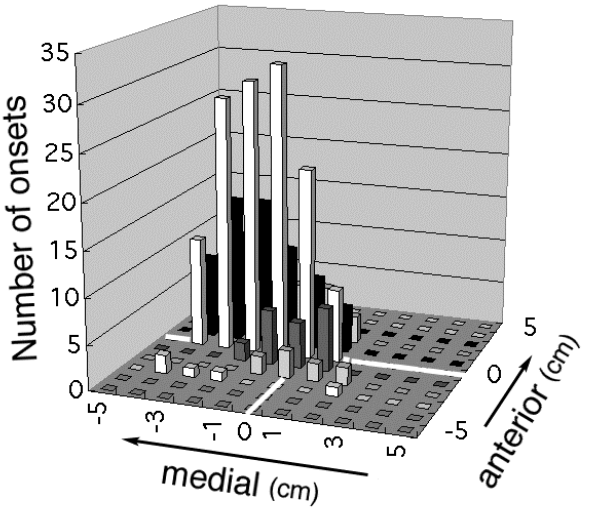

Figure 5: *Directivity of SAM virtual sensors with reference to subdural elecrtode determined as onset zone of epileptic discharge.*

The currentodensitogram from a SAM-VS depicts an electrical activity continuously in the small portion of the focused brain tissue. It closely reflects the regional magnetoelectrical behavior in the brain and requires no special conditions to apply. Even in a case of coincident multicentric spikes, where ECD analysis would be useless, this method can be applied to demonstrate these events on each currentodensitograms from spatially corresponding SAM-VSs. Moreover, the time resolution of the SAM-VS method is so high to reach a order of few milliseconds, that the origin of the discharges would be approximated only by inspecting their beginning.

4.2 ECoG/SAM temporal comparison

Among epileptic electrical events, 27% of ECoG events and 60% of SAM currentodesitogram events were recognized to coincide with each other. This means SAM-VS method appears somewhat insensitive than ECoG method. The potential changes recorded on ECoG has been estimated to reflect the cortical activities only a few millimeters under the electrode. Thus the sulcal activities would not be recorded on the ECoG [7]. Whereas most of MEG analysis, ECD analysis for example, requires phase matched neural activity as wide as at least 6 cm2 of the cortex to exhibit distinct dipole pattern on the field map [8]. SAM-VS method, with all its enhanced sensitivity and directivity, would require more or less similar order of activated cortex size for significant signal change. In contrast to ECoG method, it would reflect both surface and sulcal cortical activities. This somewhat robust feature of SAM-VS method would be beneficial to elucidate the origin and the spread process of cortical epileptic discharges, avoiding a contamination of highly localized solitary activities.

4.3 ECoG/SAM spatial comparison

When an epileptic discharge was detected in both ECoG electrode and SAM-VS simultaneously, the averaged sensor positions of SAM-VSs was 0.4 cm anterior and 1.6 cm medial in the reference frame assuming the ECoG electrode which exhibited maximal amplitude as the origin. We tried to set SAM-VSs as close as corresponding subdural grid electrodes. However about 0.3 cm difference was unavoidable due to curved surface of the cortex. Thus the difference of 0.4 cm would be acceptable localizing the origin of discharges.

On the other hand, SAM-VS method tend to be susceptible to signal strength. The noise amplitude became larger as the more attenuated magnetic signals from the deeper structures were processed. This feature of SAM-VS algorithm [3] might cause the shrinkage of signal space to the center in appearance, unless the noise component was properly assessed.

Acknowledgements

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